

## Cement Kiln Flue Gas Recovery Scrubber

### Project completed

### Participant

Passamaquoddy Tribe

### Additional Team Members

Dragon Products Company—project manager and host

HPD, Incorporated—designer and fabricator of tanks and heat exchanger

Cianbro Corporation—constructor

### Location

Thomaston, Knox County, ME (Dragon Products Company's coal-fired cement kiln)

### Technology

Passamaquoddy Technology Recovery Scrubber™

### Plant Capacity/Production

1,450 ton/day of cement; 250,000 scfm of kiln gas; and up to 274 ton/day of coal

### Coal

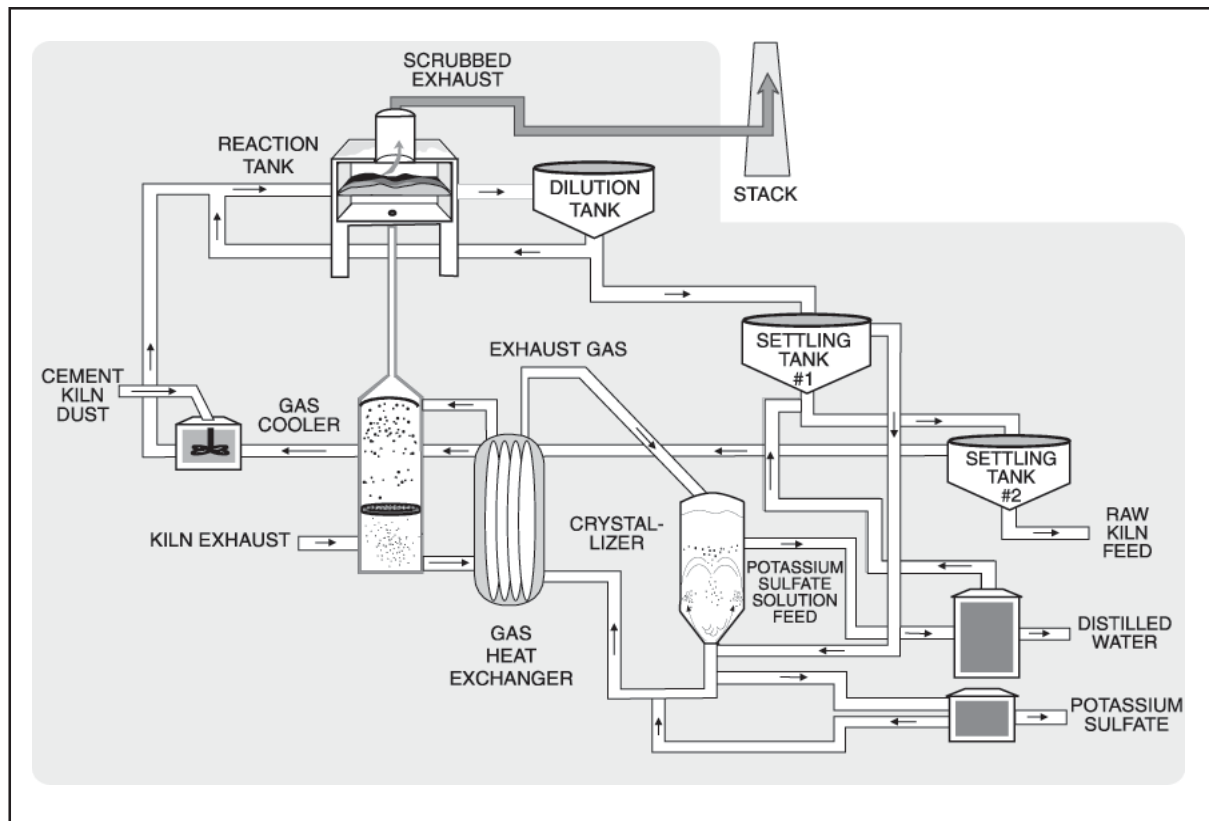
Pennsylvania bituminous, 2.5–3.0% sulfur

### Project Funding

Total	\$17,800,000	100%
DOE	5,982,592	34
Participant	11,817,408	66

### Project Objective

To retrofit and demonstrate a full-scale industrial scrubber and waste recovery system for a coal-burning wet process cement kiln using waste dust as the reagent to accomplish 90–95% SO<sub>2</sub> reduction using high-sulfur eastern coals; and to produce commercial, potassium-based fertilizer by-products.

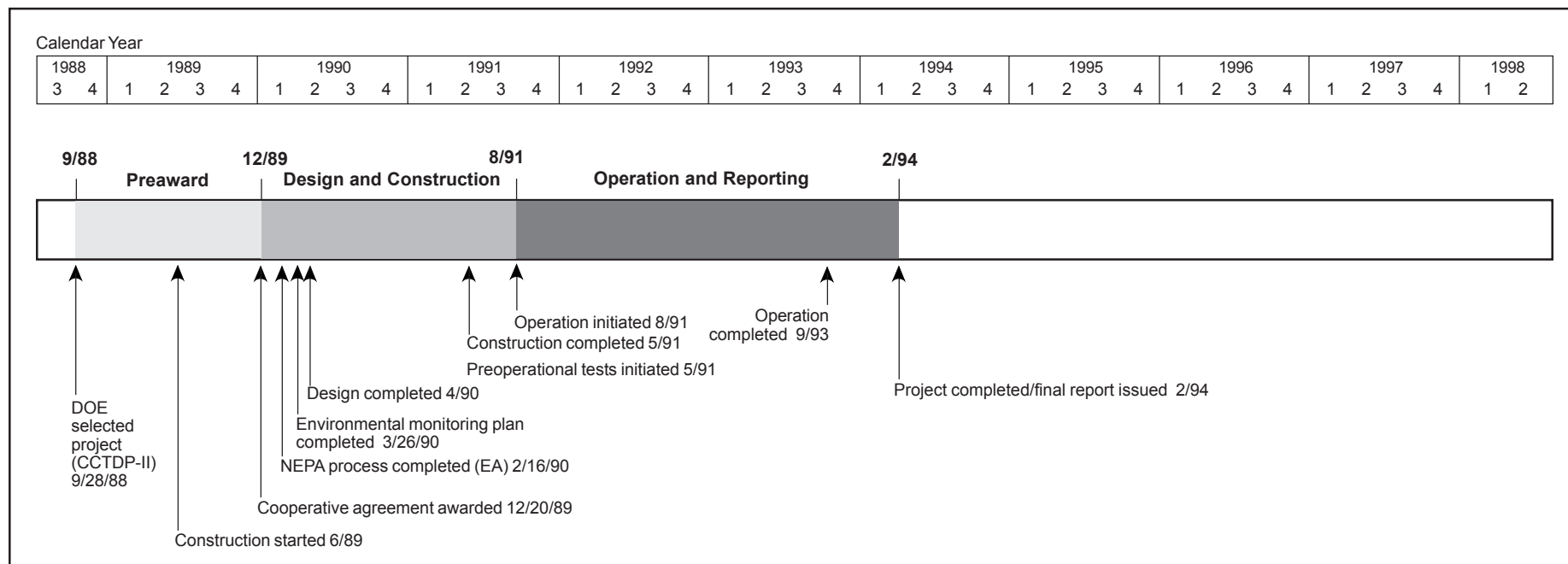


### Technology/Project Description

The Passamaquoddy Technology Recovery Scrubber™ uses cement kiln dust (CKD), an alkaline-rich (potassium) waste, to react with the acidic flue gas. This CKD, representing about 10% of the cement feedstock otherwise lost as waste, is formed into a water-based slurry and mixed with the flue gas as the slurry passes over a perforated tray that enables the flue gas to percolate through the slurry. The SO<sub>2</sub> in the flue gas reacts with the potassium to form potassium sulfate, which stays in solution and remains in the liquid as the slurry undergoes separation into liquid and solid fractions. The solid fraction, in thickened slurry form and freed of the potassium and other alkali constituents, is returned to the kiln as feedstock (it is the alkali content that makes the CKD unusable as feedstock). No dewatering is necessary for the wet process used at the Dragon Products Company cement plant.

The liquid fraction is passed to a crystallizer that uses waste heat in the flue gas to evaporate the water and recover dissolved alkali metal salts. A recuperator lowers the incoming flue gas temperature to prevent slurry evaporation, enables the use of low-cost fiberglass construction material, and provides much of the process water through condensation of exhaust gas moisture.

The Passamaquoddy Technology Recovery Scrubber™ was constructed at the Dragon Products plant in Thomaston, Maine, a plant that can process approximately 450,000 ton/yr of cement. The process was developed by the Passamaquoddy Indian Tribe while it was seeking ways to solve landfill problems, which resulted from the need to dispose of CKD from the cement-making process.



## Results Summary

### Environmental

- The SO<sub>2</sub> removal efficiency averaged 94.6% during the last several months of operation and 89.2% for the entire operating period.
- The NO<sub>x</sub> removal efficiency averaged nearly 25% during the last several months of operation and 18.8% for the entire operating period.
- All of the 250 ton/day CKD waste produced by the plant was renovated and reused as feedstock, which resulted in reducing the raw feedstock requirement by 10% and eliminating solid waste disposal costs.
- Particulate emission rates of 0.005–0.007 gr/scf, about one-tenth that allowed for cement kilns, were achieved with dust loadings of approximately 0.04 gr/scf to the scrubber.
- Pilot testing conducted at U.S. Environmental Protection Agency laboratories under Passamaquoddy Technology, L.P. sponsorship showed 98% HCl removal.

- On three different runs, VOC (as represented by alpha-pinene) removal efficiencies of 72.3, 83.1, and 74.5% were achieved.
- A reduction of approximately 2% in CO<sub>2</sub> emissions was realized through recycling of the CKD.

### Operational

- During the last operating interval, April to September 1993, recovery scrubber availability (discounting host site downtime) steadily increased from 65% in April 1993 to 99.5% in July 1993.

### Economic

- Capital costs are approximately \$10,090,000 (1990\$) for a recovery scrubber to control emissions from a 450,000-ton/yr wet process plant, with a simple pay-back estimated in 3.1 years.
- Operation and maintenance costs, estimated at \$500,000/yr, plus capital and interest costs, are generally offset by avoided costs associated with fuel, feedstock, and waste disposal and with revenues from the sale of fertilizer.

## Project Summary

The Passamaquoddy Technology Recovery Scrubber™ is a unique process that achieves efficient acid gas and particulate control through effective contact between flue gas and a potassium-rich slurry composed of waste kiln dust. Flue gas passes through the slurry as it moves over a special sieve tray. This results in high SO<sub>2</sub> and particulate capture, some NO<sub>x</sub> reduction, and sufficient uptake of the potassium (an unwanted constituent in cement) to allow the slurry to be recycled as feedstock. Waste cement kiln dust, exhaust gases (including waste heat), and wastewater are the only inputs to the process. Renovated cement kiln dust, potassium-based fertilizer, scrubbed exhaust gas, and distilled water are the only proven outputs. There is no waste.

The scrubber was evaluated over three basic operating intervals dictated by winter shutdowns for maintenance and inventory and 14 separate operating periods (within these basic intervals) largely determined by unforeseen host-plant maintenance and repairs and a depressed cement market. Over the period August 1991 to September 1993, more than 5,300 hours were logged, 1,400 hours in the first operating interval, 1,300 hours in the second interval, and 2,600 hours in the third interval. Sulfur loadings varied significantly over the operating periods due to variations in feedstock and operating conditions.

### Operational Performance

Several design problems were discovered and corrected during startup. No further problems were experienced in these areas during actual operation.

Two problems persisted into the demonstration period. The mesh-type mist eliminator, which was installed to prevent slurry entrainment in the flue gas, experienced plugging. Attempts to design a more efficient water spray for cleaning failed. However, replacement with a chevron-type mist eliminator prior to the third operating interval was effective. Potassium sulfate pelletization proved to be a more difficult problem. The cause was eventually isolated and found to be excessive water entrainment due to carry-over of gypsum and syngenite. Hydroclones were installed in the crystallizer circuit to separate the very fine gypsum and syngenite crystals from the much coarser

potassium sulfate crystals. Although the correction was made, it was not completed in time to realize pellet production during the demonstration period. After all modifications were completed, the recovery scrubber entered into the third and final operating interval—April to September 1993. During this interval, recovery scrubber availability (discounting host site downtime) steadily increased from 65% in April to 99.5% in July.

### Environmental Performance

An average 250 ton/day of CKD waste generated by the Dragon Products plant was used as the sole reagent in the recovery scrubber to treat approximately 250,000 scfm of flue gas. All the CKD, or approximately 10 ton/hr, was renovated and returned to the plant as feedstock and mixed with about 90 ton/hr of fresh feed to make up the required

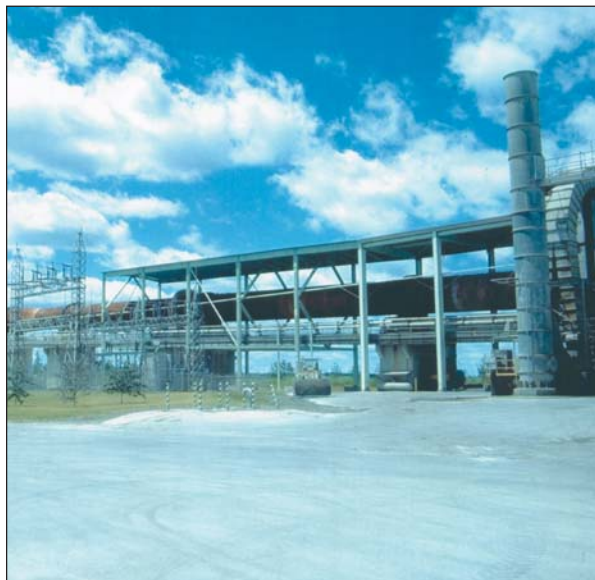
100 ton/hr. The alkali in the CKD was converted to potassium-based fertilizer, eliminating all solid waste. Exhibit 3-50 lists the number of hours per operating period, SO<sub>2</sub> and NO<sub>x</sub> inlet and outlet readings in pounds per hour, and removal efficiency as a percentage for each operating period.

Average removal efficiencies during the demonstration period were 89.2% for SO<sub>2</sub> and 18.8% for NO<sub>x</sub> emissions. No definitive explanation for the NO<sub>x</sub> control mechanics was available at the conclusion of the demonstration.

Aside from the operating period emissions data, an assessment was made of inlet SO<sub>2</sub> load impact on removal efficiency. For SO<sub>2</sub> inlet loads in the range of 100 lb/hr or less, recovery scrubber removal efficiency averaged 82.0%. For SO<sub>2</sub> inlet loads in the range of 100–200 lb/hr,

**Exhibit 3-50**  
**Summary of Emissions and Removal Efficiencies**

Operating Period	Operating Time (hr)	Inlet (lb/hr)		Outlet (lb/hr)		Removal Efficiency (%)	
		SO <sub>2</sub>	NO <sub>x</sub>	SO <sub>2</sub>	NO <sub>x</sub>	SO <sub>2</sub>	NO <sub>x</sub>
1	211	73	320	10	279	87.0	12.8
2	476	71	284	11	260	84.6	08.6
3	464	87	292	13	251	85.4	14.0
4	259	131	252	16	165	87.6	34.5
5	304	245	293	28	243	88.7	17.1
6	379	222	265	28	208	87.4	21.3
7	328	281	345	28	244	90.1	29.3
8	301	124	278	10	188	91.8	32.4
9	314	47	240	7	194	85.7	19.0
10	402	41	244	6	218	86.1	10.5
11	460	36	315	6	267	83.4	15.0
12	549	57	333	2	291	95.9	12.4
13	464	86	288	4	223	95.0	22.6
14	405	124	274	9	199	92.4	27.4
<b>Total operating time</b>		<b>5,316</b>					
<b>Weighted Average</b>		<b>109</b>	<b>289</b>	<b>12</b>	<b>234</b>	<b>89.2</b>	<b>18.8</b>



The Passamaquoddy Technology Recovery Scrubber™ was successfully demonstrated at Dragon Products Company's cement plant in Thomaston, Maine.

removal efficiency increased to 94.1% and up to 98.5% for loads greater than 200 lb/hr.

In compliance testing for Maine's Department of Environmental Quality, the recovery scrubber was subjected to dust loadings of approximately 0.04 gr/scf and demonstrated particulate emission rates of 0.005–0.007 gr/scf—less than one-tenth the current allowable limit.

### Economic Performance

The estimated “as-built” capital cost to reconstruct the Dragon Products prototype, absent the modifications, is \$10,090,000 in 1990 dollars.

Annual operating and maintenance costs are estimated at \$500,000. Long-term annual maintenance costs are estimated at \$150,000. Power costs, estimated at \$350,000/yr, are the only significant operating costs. There are no costs for reagents or disposal, and no dedicated staffing or maintenance equipment is required.

The simple payback on the investment is projected in as little as 3.1 years considering various revenues and avoided costs that may be realized by installing a recovery

scrubber similar in size to the one used at Dragon Products. In making this projection, \$6,000,000 was added to the “as-built” capital costs to allow for contingency, design/permitting, construction interest, and licensing fees.

### Commercial Applications

Of the approximately 2,000 Portland cement kilns in the world, about 250 are in the United States and Canada. These 250 kilns emit an estimated 230,000 ton/yr of SO<sub>2</sub> (only three plants have SO<sub>2</sub> controls, one of which is the Passamaquoddy Technology Recovery Scrubber™). The applicable market for SO<sub>2</sub> control is estimated at 75% of the 250 installations. If full penetration of this estimated market were realized, approximately 150,000 ton/yr of SO<sub>2</sub> reduction could be achieved.

The scrubber became a permanent part of the cement plant at the end of the demonstration. A feasibility study has been completed for a Taiwanese cement plant.

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### References

*Passamaquoddy Technology Recovery Scrubber™: Final Report.* Volumes 1 and 2 (Appendices A–M. Passamaquoddy Tribe. February 1994. (Vol. 1 available from NTIS as DE94011175, Vol. 2 as DE94011176.)

*Passamaquoddy Technology Recovery Scrubber™: Public Design Report.* Report No. DOE/PC/89657-T2. Passamaquoddy Tribe. October 1993. (Available from NTIS as DE94008316.)

*Passamaquoddy Technology Recovery Scrubber™: Topical Report.* Report No. DOE/PC/89657-T1. Passamaquoddy Tribe. March 1992. (Available from NTIS as DE92019868.)

*Comprehensive Report to Congress on the Clean Coal Technology Program: Cement Kiln Flue Gas Recovery Scrubber.* Passamaquoddy Tribe. Report No. DOE/FE-0152. U.S. Department of Energy. November 1989. (Available from NTIS as DE90004462.)